APPENDIX IV:

SPECIFIC GRAVITY

1. TYPES OF SPECIFIC GRAVITY. The specific gravity of a soil mass for use in soils engineering calculations is usually expressed in three different forms: (a) the specific gravity of solids, G_s, applied to soils finer than the No. 4 sieve; (b) the apparent specific gravity, G_a; and (c) the bulk specific gravity, G_m, both (b) and (c) being applied to soils coarser than the No. 4 sieve. The specific gravity of solids is not applied to coarse particles because they normally contain voids from which air cannot be displaced unless the particles are ground into finer particles to eliminate the voids. Thus, when dealing with coarser particles it is more convenient to work with the apparent specific gravity of the particle mass. The value G_s or G_a is used in all calculations involving fundamental properties of a soil mass. The bulk specific gravity is used in special calculations, such as corrections of density and water content for soils containing gravel sizes. Definitions and detailed procedures for determining the values of specific gravity of solids, apparent specific gravity, and bulk specific gravity are given below.

2. SPECIFIC GRAVITY OF SOLIDS, a. Definition. The specific gravity of solids, G_s, of a soil is the ratio of the weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

    b. Apparatus. The apparatus should consist of the following:

       (1) Volumetric flask, 500-cc capacity

       (2) Vacuum pump, with piping and tubing for connections to each flask (as shown in Figure 2, page 4). The connection to each flask should be provided with a trap to catch any water drawn from the flask.

       (3) Oven (see Appendix I, WATER CONTENT - GENERAL)

       (4) Balance, sensitive to 0.01 g

(5)   Thermometer, range 0 to 50 C, graduated in 0.1 degree

(6) Evaporating dish

(7) Water bath

(8)   Sieve, U. S. Standard No. 4 conforming to ASTM Designation: E11, Standard Specifications for Sieves for Testing Purposes

c.   **Calibration of Volumetric Flask.**   The volumetric flask shall be calibrated for the weight of the flask and water at various temperatures. The flask and water are calibrated by direct weighing at the range of temperatures likely to be encountered in the laboratory. The calibration procedure is as follows:

(1)   Fill the flask with deaired-distilled (or deaired-demineralized) water to slightly below the calibration mark and place in a water bath which is at a temperature between 30 and 35 C. Allow the flask to remain in the bath until the water in the flask reaches the temperature of the water bath. This may take several hours. Remove the flask from the water bath, and adjust the water level in the flask so that the bottom of the meniscus is even with the calibration mark on the neck of the flask. Thoroughly dry the outside of the flask and remove any water adhering to the inside of the neck above the graduation; then weigh the flask and water to the nearest 0.01 g. Immediately after weighing, shake the flask gently and determine the temperature of the water to the nearest 0.1 C by immersing a thermometer to the middepth of the flask.

(2)   Repeat the procedure outlined in step (1) at approximately the same temperature. Then make two more determinations, one at room temperature and the other at approximately 5 degrees less than room temperature.

(3)   Draw a calibration curve showing the relation between temperature and corresponding weights of the flask plus water. Prepare a calibration curve for each flask used for specific gravity determinations and maintain the curves as a permanent record. A typical calibration
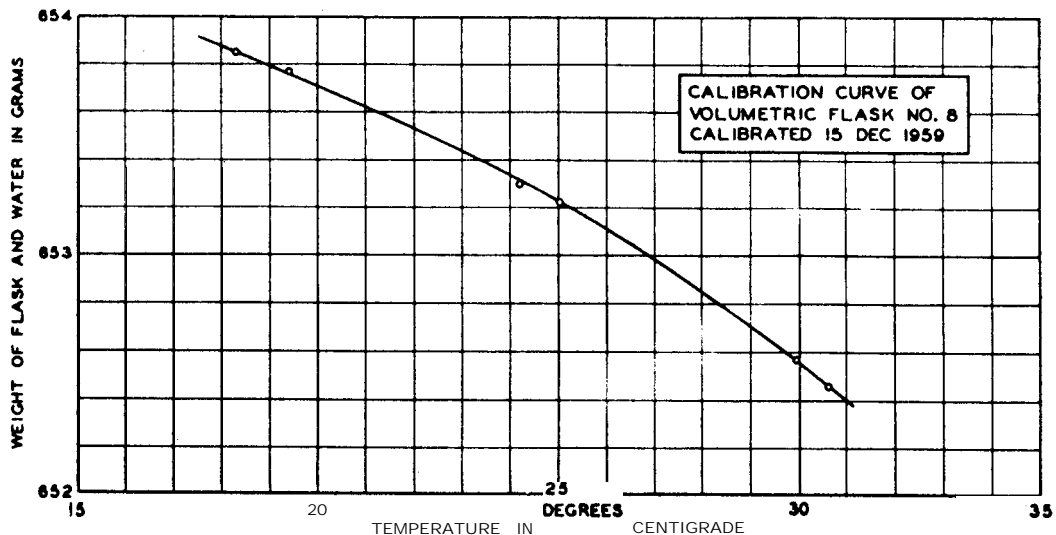
Figure 1. Typical calibration curve of volumetric flask

curve (omitting the fine grid necessary for accurate determinations) is shown in Figure 1.

d. **Preparation of Sample.** Particular care should be taken to obtain representative samples for determination of specific gravity of solids. The sample of soil may be at its natural water content or oven-dried; however, some soils, particularly those with a high organic content, are sometimes difficult to rewet after having been oven-dried. These soils may be tested without first being oven-dried, in which case the oven-dry weight of sample is determined at the end of the test. When the sample contains particles both larger and smaller than the No. 4 sieve, the sample shall be separated on the No. 4 sieve and a determination made of the specific gravity of the fine fraction and the apparent specific gravity of the coarse fraction. The specific gravity value for the sample shall be the composite specific gravity relation on the basis of the solid volume of the components. When the specific gravity value is to be used in calculations in connection with the hydrometer analysis (see Appendix V, GRAIN-SIZE ANALYSIS), the specific gravity shall be

determined on that portion of the **soil used for the hydrometer analysis (usually that which passes the No. 200 sieve). It may be necessary to use other liquids such as kerosene) in lieu of distilled water for testing soils containing soluble salts.**

e. Procedure, (1) Soils at natural water content. The procedure for determining the specific gravity of soils at natural water content shall consist of the following steps:
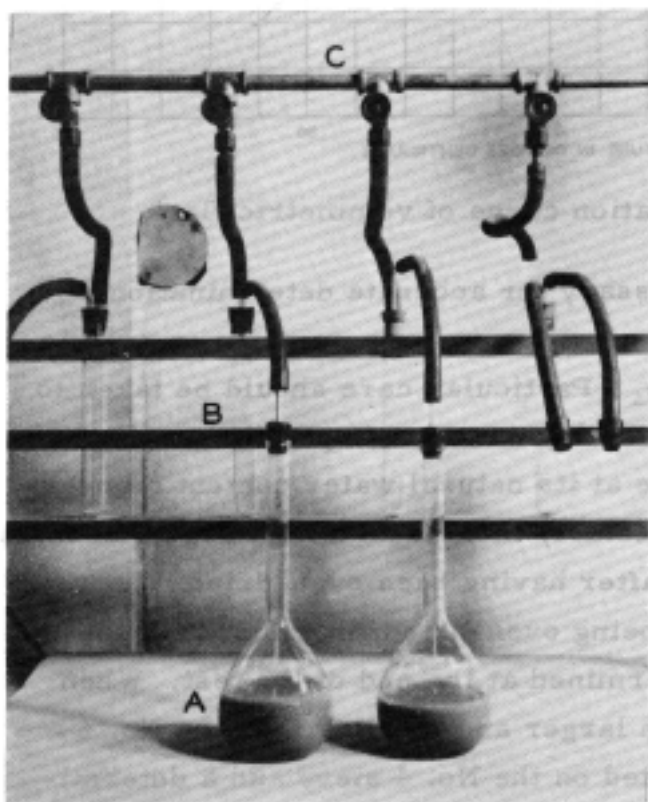

Figure 2. Evacuating air from samples in determination of specific gravity. A, flask; B, splash trap; C, vacuum line

(a) Record all identifying information for the sample such as project, boring number, sample number, and other pertinent data, on a data sheet (see Plate IV-1 for suggested form).

(b) Place a representative sample of soil equivalent to approximately 50 to 80 g oven-dry weight in a dish and, by means of a spatula, mix with sufficient distilled or demineralized water to form a slurry. Place the slurry in a volumetric flask and fill the flask approximately half full with distilled water.

(c) Connect the flask to the vacuum line as shown in Figure 2 and apply a vacuum of approximately 29.0 in.

mercury. Agitate the flask gently at intervals during the evacuation process; commercially available mechanical agitators have   used for

this purpose. The length of time that vacuum should be applied will depend on the type of soil being tested. Soils of high plasticity and organic †
soils usually require 6 to 8 hr; some soils may require less time for removal of air but this should be verified by experimentation. To ensure continuous boiling, the temperature of the flask and contents may be elevated somewhat above room temperature by immersing in a water bath at approximately 35 C. Alternatively, entrapped air may be removed by boiling‡ the suspension gently for at least 10 min while occasionally rolling the flask to assist in the removal of air. The boiling process should be observed closely as loss of material may occur. Allow flask and contents to cool, preferably overnight, before filling and checking.

(d) Fill the flask with deaired distilled water to about
3/4 in. below the 500-cc graduation and apply a vacuum slightly less than that which will cause vigorous boiling (as vigorous boiling may result in a loss of solids). To determine if the suspension is deaired, slowly release the vacuum and observe the lowering of the water surface in the neck of the flask. If the water surface is lowered less than 1/8 in., the suspension can be considered sufficiently deaired.

(e) Fill the flask until the bottom of the meniscus is coincident with the calibration line on the neck of the flask. Thoroughly dry the outside of the flask and *remove* the moisture *on* the inside of the neck by wiping with a paper towel. Weigh the flask and contents to the nearest 0.01 g. Immediately after weighing, stir the suspension to assure uniform temperature, and determine the temperature of the suspension to the nearest 0.1 C by immersing a thermometer to the middepth of the flask.

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† Air removal from organic soils usually cannot be accomplished by the application of vacuum. In this case it will be necessary to boil the suspension contained in the flask for about 30 min, adding distilled or demineralized water carefully from time to time to prevent boiling the sample dry. The flask should at all times be approximately half full.

‡ Use of indirect heat such as a sand bath is recommended.

(f)   Carefully transfer the contents of the flask to an evaporating dish. Rinse the flask with distilled water to ensure removal of all of the sample from the flask. Oven-dry the sample to a constant weight at a temperature of. 110 ± 5 C. Allow the soil to cool to room temperature in a desiccator and determine the weight of the soil to the nearest 0.01 g.

(g)   Record all weights on the data sheet.

(2) Oven-dried soils.   The procedure for determining the specific gravity of solids for oven-dried soils shall consist of the following steps:

(a)   Record information identifying the sample on the data sheet (see Plate IV- 1).

(b)   Oven-dry the soil to a constant weight at 110 ± 5 C and cool it to room temperature in a desiccator. Select a representative sample of between 50 g (for cohesive soils) and 150 g (for cohesionless soils) and weigh the sample to the nearest 0.01 g. After weighing, transfer the soil to a volumetric flask, taking care not to lose any material during this operation. To avoid possible loss of preweighed soil, the sample may be weighed after transfer to the flask. Fill the flask approximately half full with de-aired distilled water and allow the suspension to stand overnight.

(c)   Connect the flask to the vacuum line and apply a vacuum of approximately 29.0 in. mercury for approximately 2 to 4 hr. Entrapped air may also be removed by boiling as previously discussed; however, the process should be observed closely to avoid loss of material during boiling. Allow flask and contents to cool, preferably overnight, before filling and checking.

(d)   Perform the remainder of the test as outlined in paragraph 2e(1)(d) and 2e(1)(e).

(e)   Record all weights on the data sheet.

f.   Computations.   The following quantities are obtained by direct weighing :

(1)   Weight of flask plus water plus solids at test temperature = W_{bws} in grams.

(2)   Weight of tare plus dry soil in grams. The tare weight is subtracted from this value to obtain the weight of dry soil, W_s. The specific gravity of solids is computed to two decimal places by the formula:

$$G_s = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$$

where

K   = correction factor based on the density of water at 20 C (see Table IV-1). Unless otherwise required, specific gravity values reported shall be based on water at 20 C.

W_{bw} = weight of flask plus water at test temperature in grams (obtained from calibration curve as shown in Figure 1).

3.   APPARENT AND BULK SPECIFIC GRAVITY.   a.   Definitions.   The apparent specific gravity, G_a, of a soil is the ratio of the weight in air of a given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

The bulk specific gravity of a soil, G_m, is the ratio of the weight in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

b.   Apparatus.   The apparatus should consist of the following:

(1)   Balance, having capacity of 5 kg or more and sensitive to 1.0 g

(2)   Wire basket of No. 6 mesh, approximately 8 in. in diameter and 8 in. high

(3)   Suitable container for immersing the wire basket in water, and suitable apparatus for suspending the wire basket from

Table IV-1

Relative Density of Water and Correction

Factor (K) for Various Temperatures

Temp °C	Relative Density	Correction Factor, K	Temp °C	Relative Density	Correction Factor, K	Temp °C	Relative Density	Correction Factor, K
18.0	0.99862	1.0004	23.0	0.99756	0.9993	28.0	0.99626	0.9980
.1	60	4	.1	54	3	.1	23	0
.2	58	4	.2	51	3	.2	20	0
.3	56	3	.3	49	3	.3	17	0
.4	54	3	.4	46	2	.4	14	79
.5	52	3	.5	44	2	.5	11	9
.6	50	3	.6	42	2	.6	08	9
.7	49	3	.7	39	2	.7	06	8
.8	47	2	.8	37	1	.8	03	8
.9	45	2	.9	34	1	.9	00	8
19.0	0.99843	1.0002	24.0	0.99732	0.9991	29.0	0.99597	0.9977
.1	41	2	.1	29	1	.1	94	7
.2	39	2	.2	27	0	.2	91	7
.3	37	1	.3	24	0	.3	88	6
.4	35	1	.4	22	0	.4	85	6
.5	33	1	.5	20	0	.5	82	6
.6	31	1	.6	17	89	.6	79	6
.7	29	1	.7	14	9	.7	76	5
.8	27	0	.8	12	9	.8	73	5
.9	25	0	.9	09	9	.9	70	5
20.0	0.99823	1.0000	25.0	0.99707	0.9988	30.0	0.99567	0.9974
.1	21	0	.1	04	8	.1	64	4
.2	19	0	.2	02	8	.2	61	4
.3	17	0.9999	.3	699	8	.3	58	3
.4	15	9	.4	97	7	.4	55	3
.5	13	9	.5	94	7	.5	52	3
.6	10	9	.6	91	7	.6	49	3
.7	08	8	.7	89	7	.7	46	2
.8	06	8	.8	87	6	.8	43	2
.9	04	8	.9	84	6	.9	40	2
21.0	0.99802	0.9998	26.0	0.99681	0.9986	31.0	0.99537	0.9971
.1	00	8	.1	78	6	.1	33	1
.2	798	8	.2	76	5	.2	30	1
.3	96	7	.3	73	5	.3	27	0
.4	93	7	.4	70	5	.4	24	0
.5	91	7	.5	68	4	.5	21	0
.6	89	7	.6	65	4	.6	18	69
.7	87	6	.7	63	4	.7	15	9
.8	85	6	.8	60	4	.8	12	9
.9	83	6	.9	57	3	.9	09	9
22.0	0.99780	0.9996	27.0	0.99654	0.9983	32.0	0.99505	0.9968
.1	78	6	.1	51	3	.1	02	8
.2	75	5	.2	48	2	.2	499	8
.3	73	5	.3	46	2	.3	96	7
.4	70	5	.4	43	2	.4	93	7
.5	68	5	.5	40	2	.5	90	7
.6	65	4	.6	37	1	.6	86	6
.7	63	4	.7	34	1	.7	83	6
.8	61	4	.8	32	1	.8	80	6
.9	58	4	.9	29	1	.9	77	5

* Note: Relative density of water based on density of water at 4 C equal to unity. The values given are numerically equal to the absolute density in grams/milliliter (for soil testing purposes, g/ml ≈ g/cc). Data obtained from Smithsonian Tables, compiled by various authors.

Correction factor, K, is found by dividing the relative density of water at the test temperature by the relative density of water at 20 C.

the center of the balance scale pan

(4) Thermometer, range 0 to 50 C, graduated in 0.1 degree

c. <u>Sample.</u> The material to be tested shall be separated on the No. 4 sieve and the material retained on the sieve used for the test. A representative sample of approximately 2 kg is required. Samples may be air -dried; however, oven-drying the sample before the test may affect the results and should be avoided when possible.

<u>d.</u> <u>Procedure.</u> The procedure for determining the apparent and bulk specific gravity of soils retained on the No. 4 sieve shall consist of the following steps:

(1) Record information identifying the specimen on the data sheet (see Plate IV-1).

(2) Wash the specimen thoroughly to remove dust or other coatings from the surfaces of the particles.

(3) Immerse the specimen in water at 15 to 25 C for a period of 24 hr.

(4) Remove the specimen from the water and roll it in a large absorbent cloth until all visible films of water are removed, although the surfaces of the particles may still appear to be damp. Wipe large particles individually. Take care to avoid excess evaporation during the operation of surface drying.

(5) Obtain the weight in grams of the saturated surface-dry specimen. The specimen in this and subsequent weighings should be weighed to the nearest 1.0 g.

(6) Immediately after weighing, place the specimen in the wire basket and determine the weight of the specimen in water. Deter - mine and record the temperature of the water in which the specimen is immersed.

(7) Oven-dry the specimen to a constant weight at 110±5 C. After cooling to room temperature, weigh the specimen.

(8) Record all weights on the data sheet.

    e.   Computations.   The following quantities are obtained by direct weighing:

    (1) Weight of tare plus oven-dried soil in grams. The tare weight is subtracted from this value to obtain the weight of dry soil, A, on the data sheet.

    (2) Weight of tare plus saturated surface-dry soil in grams. The tare weight is subtracted from this value to obtain the weight of saturated surface-dry soil, B.

    (3)   Weight of wire basket plus saturated soil in water in grams. The weight of wire basket in water is subtracted from this value to obtain the weight of saturated soil in water, C.

    The apparent specific gravity is computed to two decimal places by the formula:

$$G_a = \frac{AK}{A - C}$$

where

    K = correction factor based on the density of water at 20 C (see Table IV-i).

    The bulk specific gravity is computed to two decimal places by the formula:

$$G_m = \frac{AK}{B - C}$$

    When a soil is composed of particles both larger and smaller than the No. 4 sieve, the specific gravity of the soil for use in engineering calculations shall be computed as follows:

$$G = \frac{100}{\dfrac{\% \text{ passing No. 4 sieve}}{G_s} + \dfrac{\% \text{ retained on No. 4 sieve}}{G_a}}$$

4.   POSSIBLE ERRORS. Following are possible errors that would cause inaccurate determinations of specific gravity:

    a. Specific Gravity of Solids. (1) Imprecise weighing of

flask and contents.   Since the computation of the specific gravity of solids is based on a difference in weights which is small in comparison with the weights themselves, the same balance should be used for calibrating the volumetric flask and for determining the specific gravity whenever the calibration curve is used.

(2)   Temperature of flask and contents not uniform. Both in calibrating the flask and determining the specific gravity, utmost care should be taken to insure that measured temperatures are representative of the flask and contents during the times when the weighings are made.

(3) Flask not clean.   The calibration curve will not remain valid if dirt accumulation changes the weight of the flask. Also, if the inside of the neck is not clean, an irregular meniscus may form,

(4)   Moisture on outside of flask or inside of neck.   When calibrating the flask for a temperature lower than room temperature, there is a tendency for condensation to form on the flask despite careful drying and rapid weighing.   Whenever possible, weighing should be done at approximately the same temperature as that of the flask.

(5)   Meniscus not coincident with mark on neck of flask.   One drop of water too much makes an error of approximately 0.05 g. This error can be minimized by taking the average of several readings at the same temperature.   When the suspension is opaque, a strong light behind the neck is helpful in seeing the bottom of the meniscus.

(6) Use of water containing dissolved solids.   It is essential that distilled or demineralized water be used exclusively to insure the continued validity of the flask calibration curve.

(7)   Incomplete removal of entrapped air from soil suspension. This is the most serious source of error in the specific gravity determination and will tend to lower the computed specific gravity.   The suspension must be thoroughly evacuated or boiled and the absence of entrapped air verified as described in paragraph 2e(1)(d). (It should be noted that air dissolved in the water will not affect the results, so it is not

necessary to apply vacuum to the flask when calibrating or after filling the flask to the calibration mark.)

(8)   Gain in moisture of oven-dried s ecimen before weighing. If the specimen is oven-dried before the specific   ravity determination, it must be protected against a gain in moisture untiI it can be weighed and placed in the flask.

(9)   Loss of material from oven-dried specimen.   If the specimen is oven-dried and weighed before being placed in the flask, any loss of material will lower the computed specific gravity.

b.   Apparent and Bulk Specific Gravity.   (1) Loss of moisture from saturated surface-dry particles before weighing. Unless the saturated surface-dry material is weighed promptly, evaporation may cause an increase in the computed bulk specific gravity,

(2)   Failure to correct for the change in density of water with temperature.   This correction is often overlooked when computing either the apparent or bulk specific gravity.

SPECIFIC GRAVITY TESTS

Date _____

Project _____

Boring No. _____

SPECIFIC GRAVITY OF SOLIDS (G_s)

Sample or Specimen No.					
Flask No.					
Temperature of water and soil, T, °C					
Dish No.					
Dish + dry soil					
Dish					
Dry soil	W_s				
Flask + water at T, °C	W_{bw}				
$W_s + W_{bw}$					
Flask + water + immersed soil	W_{bws}				
Displaced water, $W_s + W_{bw} - W_{bws}$					
Correction factor	K				
$(W_s K) + (W_s + W_{bw} - W_{bws})$	G_s				

Left side label: Weight in grams

APPARENT (G_a) AND BULK (G_m) SPECIFIC GRAVITY

Sample or Specimen No.					
Temperature of water and soil, T, °C					
Tare + saturated surface-dry soil					
Tare					
Saturated surface-dry soil	B				
(Wire basket + soil) in water					
Wire basket in water					
Saturated soil in water	C				
Tare + dry soil					
Tare					
Dry soil	A				
Correction factor	K				
$(AK) \div (A - C)$ (Apparent)	G_a				
$(AK) \div (B - C)$ (Bulk)	G_m				

Left side label: Weight in grams

Remarks _____

Technician _____ Computed by _____ Checked by _____